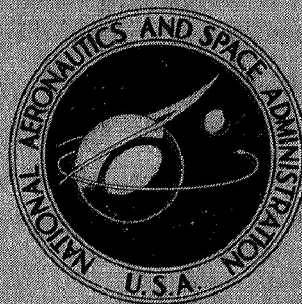


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AERODYNAMIC CHARACTERISTICS
OF SOME MODIFIED CONICAL BODIES
WITH LOW LIFT-DRAG RATIOS AT
MACH NUMBERS OF 2.30 AND 4.63

by Edwin E. Davenport

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SUMMARY

A wind-tunnel investigation was conducted at Mach numbers of 2.30 and 4.63 to determine the static aerodynamic characteristics of three 60° half-angle cone models. Configuration 1 was obtained by raking off a symmetrical cone at a base angle of 6.15° , and configurations 2 and 3 were obtained by adding flaps to a symmetrical cone. The models were tested at angles of attack from about -5° to about 20° at roll angles of 0° to -180° and at a free-stream Reynolds number of 1.09×10^6 , based on body diameter. The results showed that all three configurations produced finite values of lift-drag ratio useful for lifting planetary entry. All three configurations exhibited increases in yawing moment and side force with roll angle; thus, the capability for lateral trajectory control is provided.

INTRODUCTION

Some of the planetary-entry programs being considered by the NASA conceive the use of a high-drag vehicle capable of entering a low-density atmosphere and landing a scientific payload. (See refs. 1 and 2.) Studies show that an atmospheric-entry configuration with a low ballistic coefficient can utilize aerodynamic deceleration prior to actuation of terminal deceleration devices, such as parachutes or retrorockets, with an appreciable saving in system weight.

The blunted cone offers much promise as a high-drag atmospheric-entry configuration, and the static aerodynamic characteristics of various cone shapes are reported in references 3, 4, and 5. Other studies show that entry bodies capable of generating small but finite quantities of lift and with some means of following a prescribed trajectory will permit a shallow and controllable planetary entry.

The results of theoretical studies of right circular cones which are raked off at the base to provide asymmetry and consequent finite lift-drag ratios and which are conceived to have a flight orientation capability for trajectory control are presented in reference 3.

The experimental aerodynamic characteristics at hypersonic speeds of raked-off cones with half-angles of 35° to 40° are presented in reference 4. Data presented in reference 6 show that symmetrical cones with half-angles of 60° will produce reasonably high drag values; thus, these cones are attractive candidates for planetary entry.

This paper presents the results of a supersonic investigation of the aerodynamic characteristics of blunted 60° half-angle cones modified to provide small values of lift-drag ratio. Configuration 1 incorporates a cone with a base raked off at an angle of 6.15° . Configurations 2 and 3 are right circular cones with different sizes of flap-like aerodynamic extensions mounted asymmetrically in the periphery. The results are presented for Mach numbers of 2.30 and 4.63 for an angle-of-attack range from about -5° to about 20° .

SYMBOLS

The results are referred to the body-axis system except for lift and drag which are referred to the stability-axis system. Both body-axis and stability-axis systems are fixed in the vertical-horizontal planes regardless of the model roll angle. A sketch of the axis system is shown in figure 1.

Measurements and calculations were made in the U.S. Customary Units. They are presented herein in the International System of Units (SI) with the equivalent values given parenthetically in the U.S. Customary Units. Factors relating these two systems of units are presented in reference 7.

C_A	axial-force coefficient, $\frac{\text{Axial force}}{qS}$
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSd}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSd}$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qS}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSd}$

C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$
d	model-base reference diameter (actually an equivalent diameter for raked-off cone, 20.07 cm (7.90 inches))
L/D	lift-drag ratio
M	free-stream Mach number
q	free-stream dynamic pressure
R	free-stream Reynolds number based on d
r_b	base radius
S	base area
α	angle of attack, degrees
ϕ	angle of roll, degrees

APPARATUS

Models

Geometric characteristics of the models are shown in figure 2, and a photograph of the models is shown as figure 3. The models were machined from solid aluminum with all surfaces which were exposed to the airstream polished and aerodynamically smooth. The raked-off cone model, which had an elliptical base raked off at 6.15° , will be referred to as configuration 1. The two versions of a flapped symmetrical cone, which had a circular base, will be referred to as configurations 2 and 3. The projected area of the flaps on configuration 2 was 0.19 of the cone base area. Part of the outer flapped area was removed from configuration 2 to form configuration 3 with a resulting ratio of flapped area to base area of 0.14.

Wind Tunnel

The tests were conducted in the high Mach number test section of the Langley Unitary Plan wind tunnel with the models mounted on a sting-supported internal strain-gage balance. The test section is of the variable-pressure, return-flow type and is 1.219 meters (4 feet) square and approximately 2.134 meters (7 feet) in length. The nozzle leading to the test section is of the asymmetric sliding type, and the Mach number may be varied continuously through a range from about 2.30 to 4.63. Further details of the wind tunnel may be found in reference 8.

TESTS

All configurations were tested at Mach numbers of 2.30 and 4.63 at a Reynolds number, based on model diameter, of 1.09×10^6 . The dewpoint temperature was maintained below 239 K (-30° F) for all tests to prevent any significant condensation effects. The stagnation temperature was held at 339 K (150° F) for Mach 2.30 and 353 K (175° F) for Mach 4.63. The models were tested through an angle-of-attack range of -5° to about 20° at roll angles of 0° , -45° , -90° , and -180° . The orientations of angle of attack α and roll angle ϕ are shown in figure 1.

RESULTS AND DISCUSSION

Configuration 1 (Raked-Off Cone)

The values of axial-force coefficient C_A for configuration 1 were fairly constant over an angle-of-attack range from about -4° to 5° for Mach numbers of 2.30 and 4.63 and for the range of roll angles ϕ for which data were obtained. (See fig. 4.) Above an angle of attack of about 5° , C_A decreased with further increase of angle of attack. The level of normal-force coefficient C_N increased with increase in angle of attack and decreased as roll angle was increased negatively for both Mach number conditions. The pitching-moment coefficient C_m decreased linearly with increase in angle of attack for both Mach number conditions.

The aerodynamic characteristics with respect to the stability-axis system for configuration 1 are presented in figure 5. Lift coefficient C_L decreased with increase of angle of attack α and negative increase of ϕ . The negative increase of L/D with angle of attack was linear with L/D values of approximately -0.3 obtained for $\alpha = 20^\circ$ at $M = 2.30$. According to reference 9, this level of L/D should permit a lifting entry into the Martian atmosphere at an equivalent earth g of 10. Lift-drag ratio decreased slightly with increase in Mach number.

The static lateral aerodynamic characteristics presented in figure 6 for configuration 1 show that finite values of yawing moment and side-force coefficient are present at intermediate roll angles ($\phi = -45^\circ$ and -90°) and possibly are sufficient for cross-range control of the trajectory. Representative schlieren photographs are shown in figure 7.

Configurations 2 and 3 (Flapped Cones)

Configurations 2 and 3 of this investigation are symmetrical 60° half-angle cones with extensible trailing-edge flaps which can be extended for low-lift development at atmospheric entry. As mentioned previously, the flap area of configuration 2 was about 0.19 base area and that of configuration 3 was about 0.14 base area. All coefficients, however, were computed using the base area of the unflapped cone.

Because of the increased area of the flaps of configurations 2 and 3 and because C_A was based on the unflapped base area of the cone, large increases in C_A were produced compared with the data obtained for the symmetrical-cone configuration of reference 5. (See fig. 8.) Increase in Mach number slightly decreased the values of C_A for both configurations 2 and 3. Normal-force coefficient C_N increased linearly with angle of attack. The variation of C_m , for the reference centers used, was both linear and stable. Large absolute values of C_m were obtained at $\phi = 0^\circ$ and -180° for both flapped cones as would be expected.

The aerodynamic characteristics with respect to the stability-axis system, as presented in figure 9, again show negative increases of C_L with increase of α as was shown for the flap-retracted condition (ref. 5) and for the raked-off cone of configuration 1 (fig. 5). At $\alpha = 20^\circ$, the values of L/D were somewhat higher for configurations 2 and 3 at both test Mach numbers than for configuration 1. (Compare figs. 9 and 5.)

The trends of the static lateral aerodynamic characteristics for configuration 2 (fig. 10) are quite similar to those for configuration 1 (fig. 6). Values of rolling-moment coefficient C_l for configurations 2 and 3 were small, but values of side-force coefficient C_Y and yawing-moment coefficient C_n were finite and increased with increase in roll angle up to $\phi = -90^\circ$. Schlieren photographs were not available for all test conditions for configurations 2 and 3, but representative photographs are shown in figure 11.

CONCLUDING REMARKS

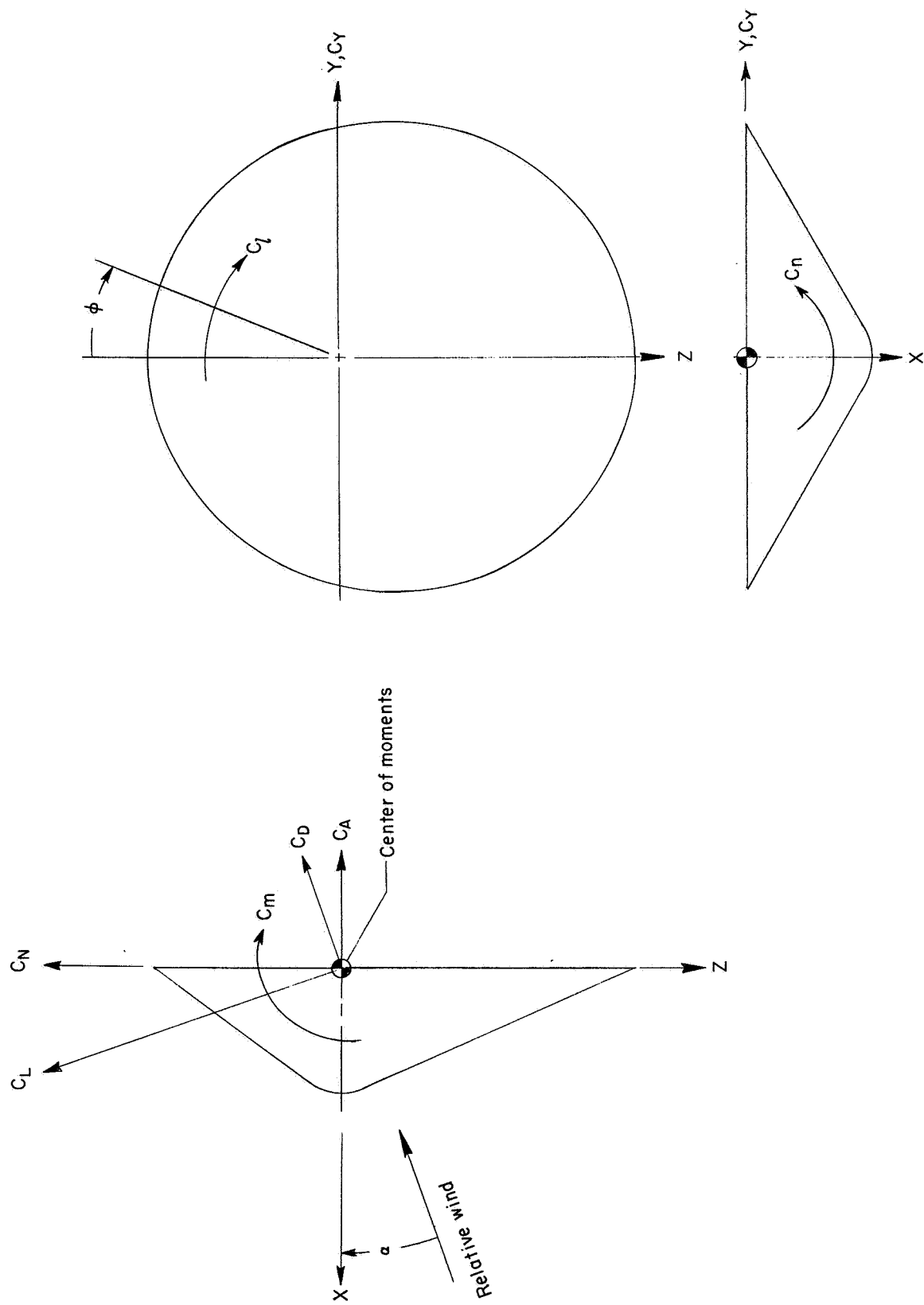
The static longitudinal and lateral aerodynamic characteristics of three blunted 60° half-angle cone models with low lift-drag ratios were obtained at Mach numbers of 2.30 and 4.63 at angles of attack from about -5° to about 20° at a Reynolds number of 1.09×10^6 , based on body diameter. The models were tested at roll angles of 0° , -45° , -90° , and -180° . The models were a 60° half-angle cone with the base raked off at 6.15° and a symmetrical 60° half-angle cone with two configurations of extensible flaps.

All three configurations produced lift-drag ratios of sufficient value for some planetary-entry considerations. The flapped configuration produced slightly higher values of lift-drag ratio than did the raked-off cone configuration. All three configurations exhibited increases in yawing moments and side force with roll angle which probably could be utilized for lateral trajectory control.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 15, 1972.

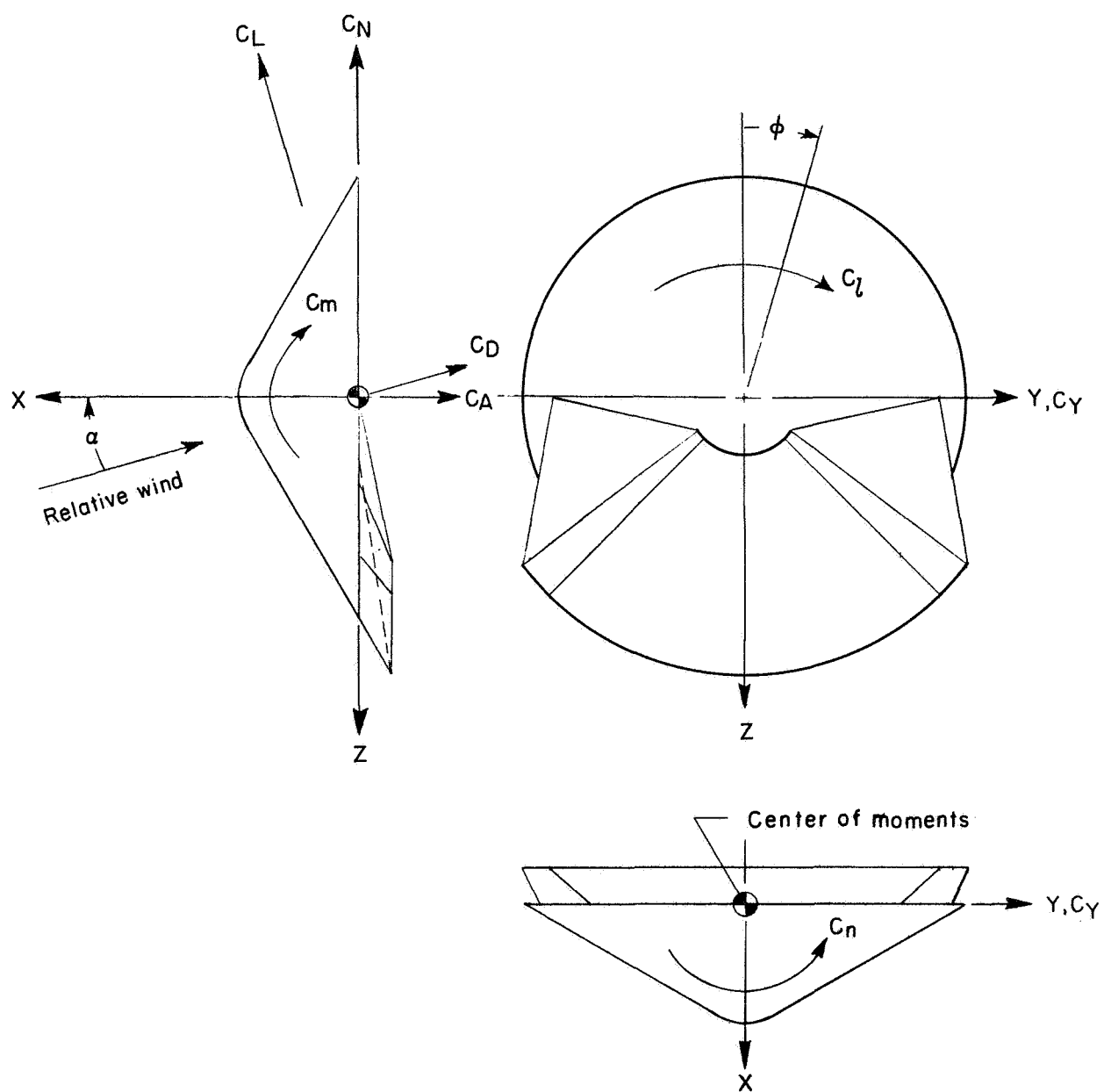
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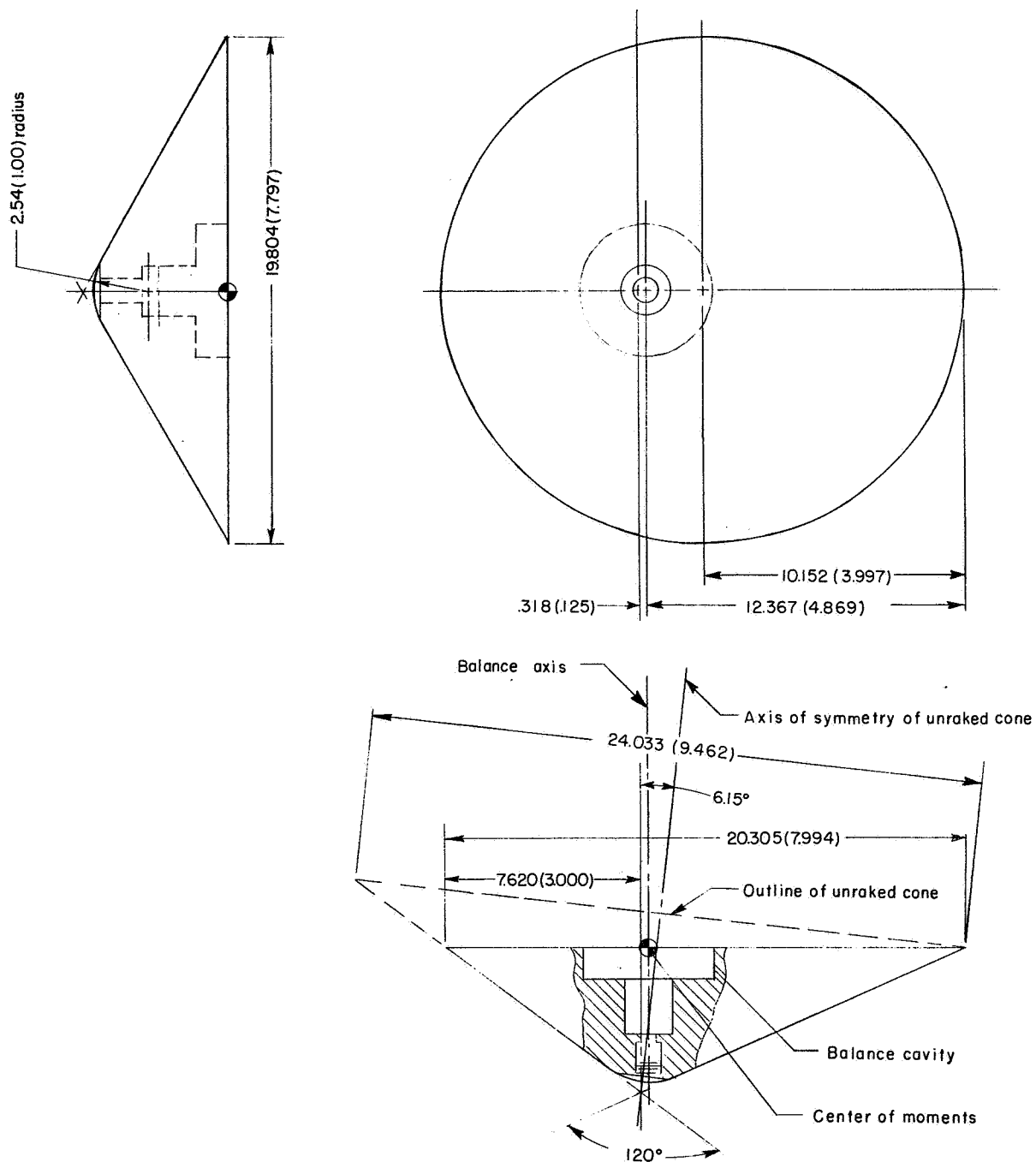
(a) Configuration 1 (raked-off cone).

Figure 1.- Sketch of axis systems. Arrows indicate positive directions of forces and moments.



(b) Configurations 2 and 3 (flapped cones).

Figure 1.- Concluded.



(a) Configuration 1 (raked-off cone). Base area = 316.076 cm^2 (48.992 in^2).

Figure 2.- Geometric characteristics of the models. All linear dimensions are given in centimeters and parenthetically in inches.

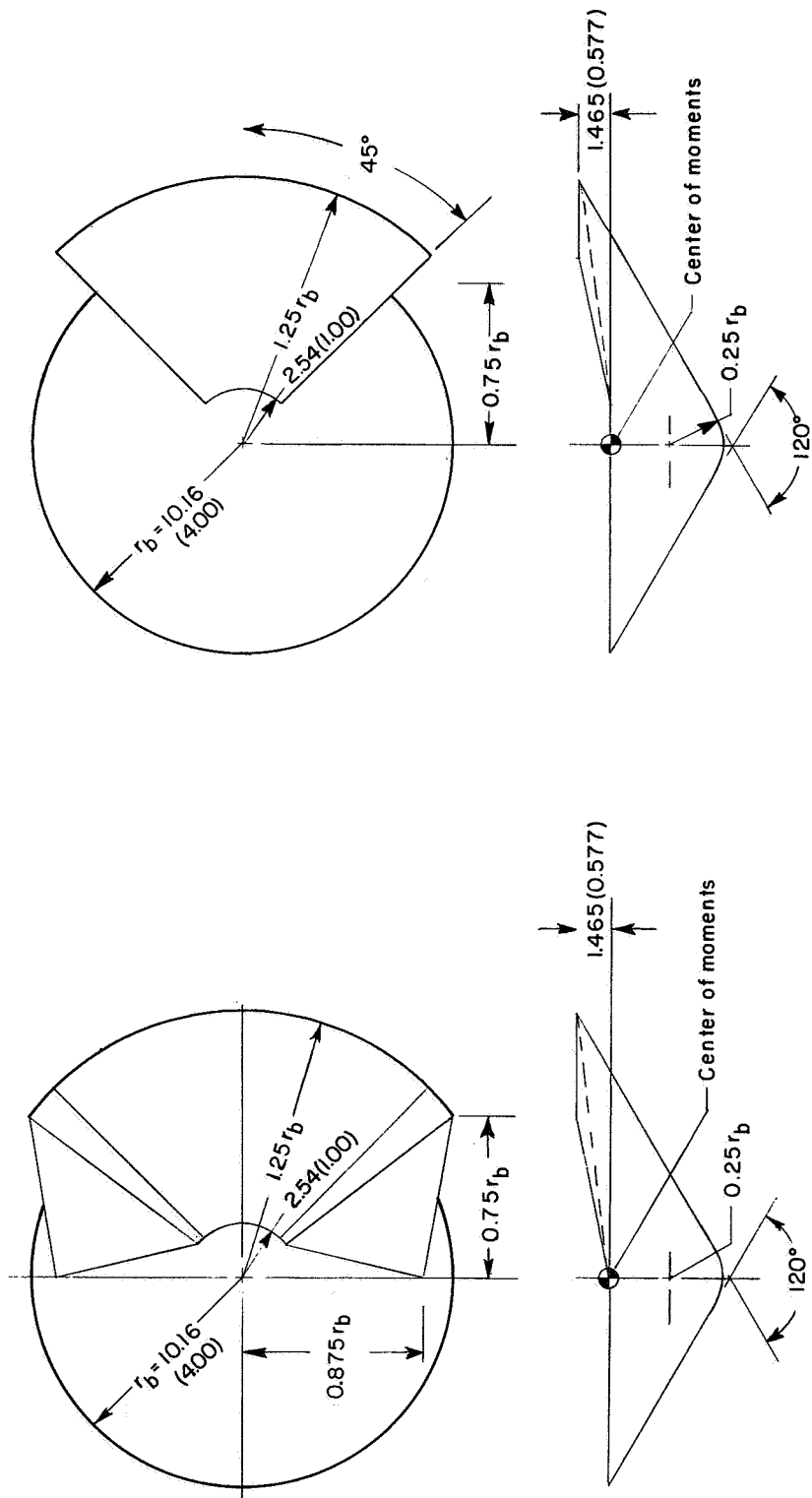


Figure 2.- Concluded.

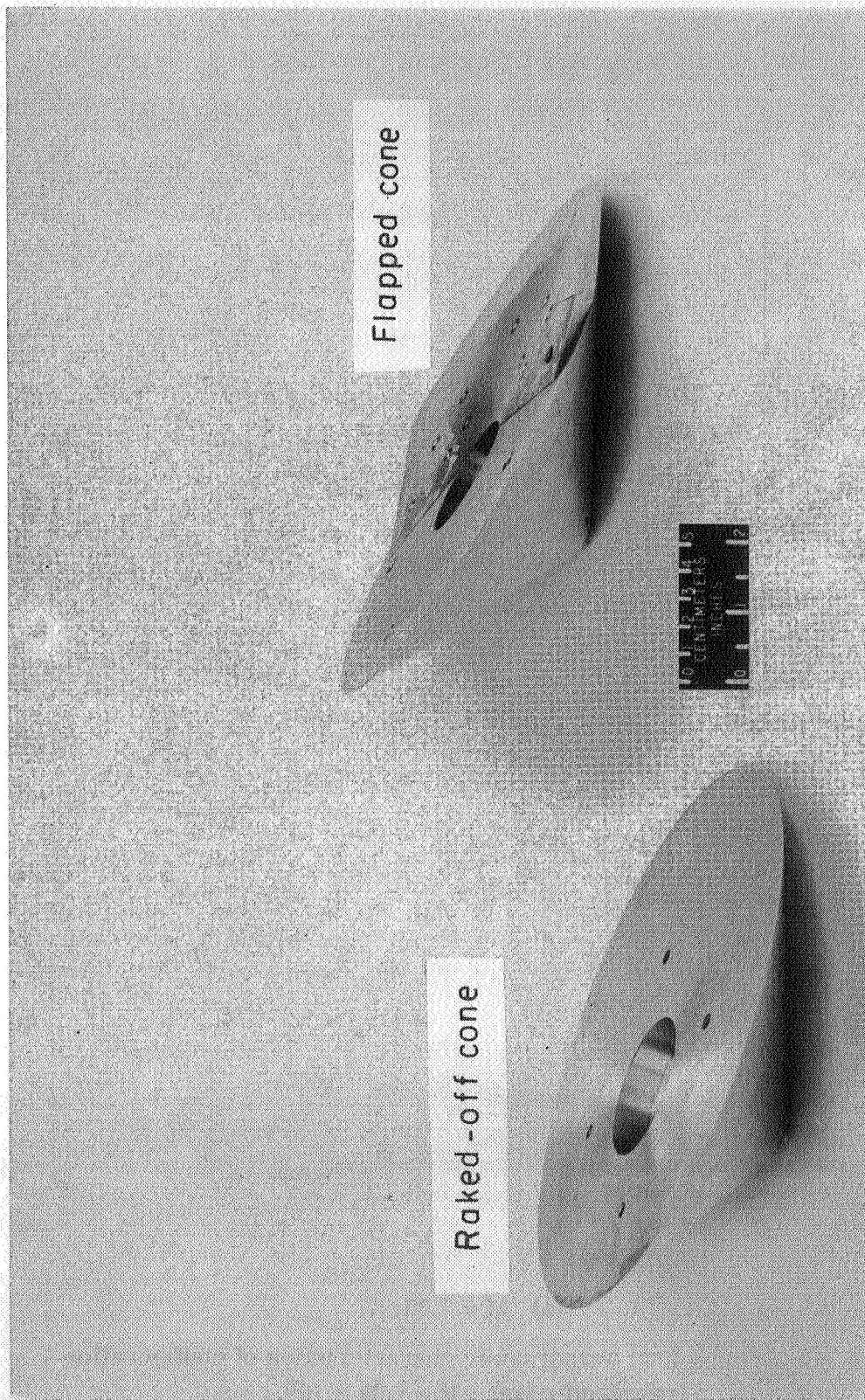
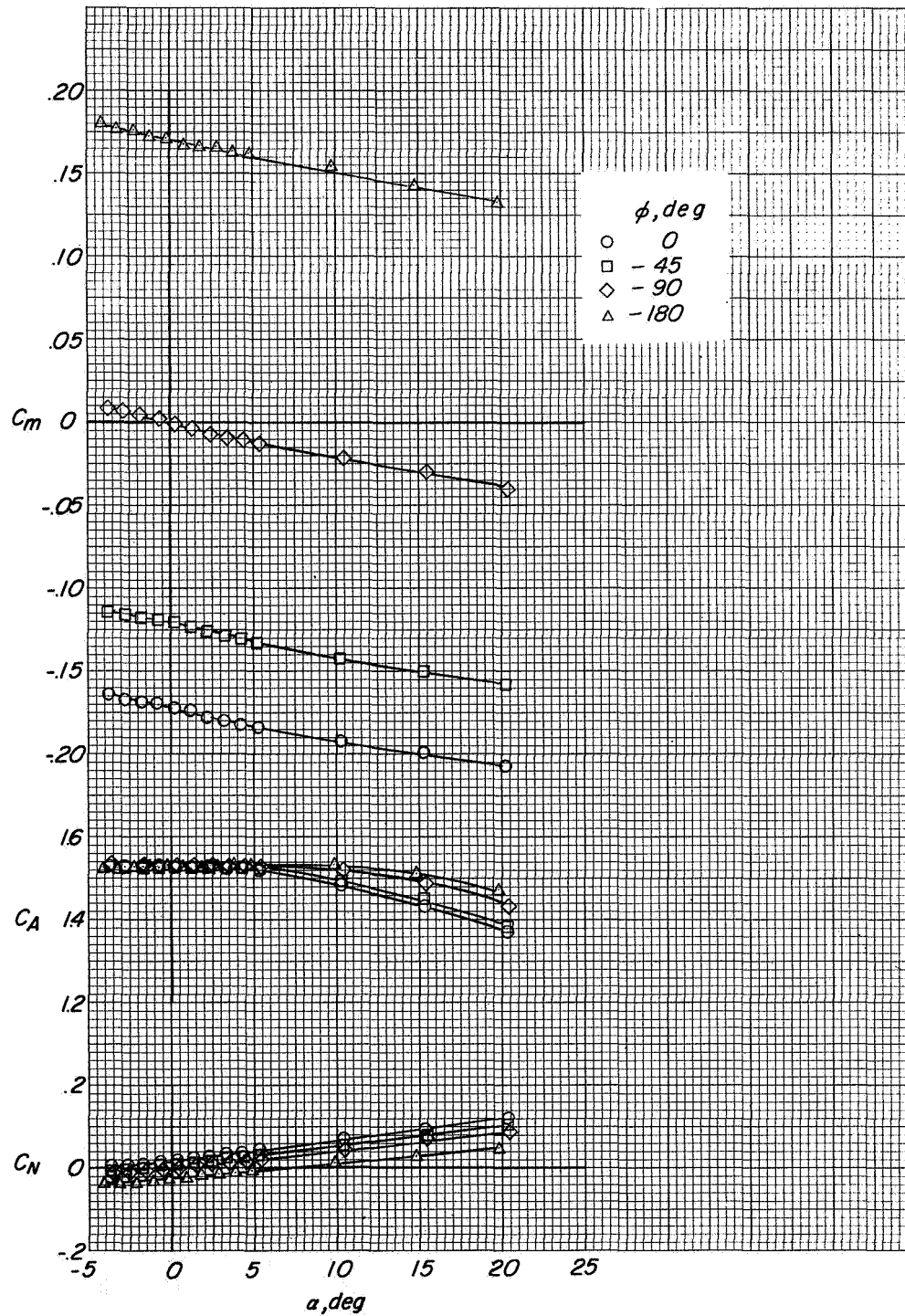
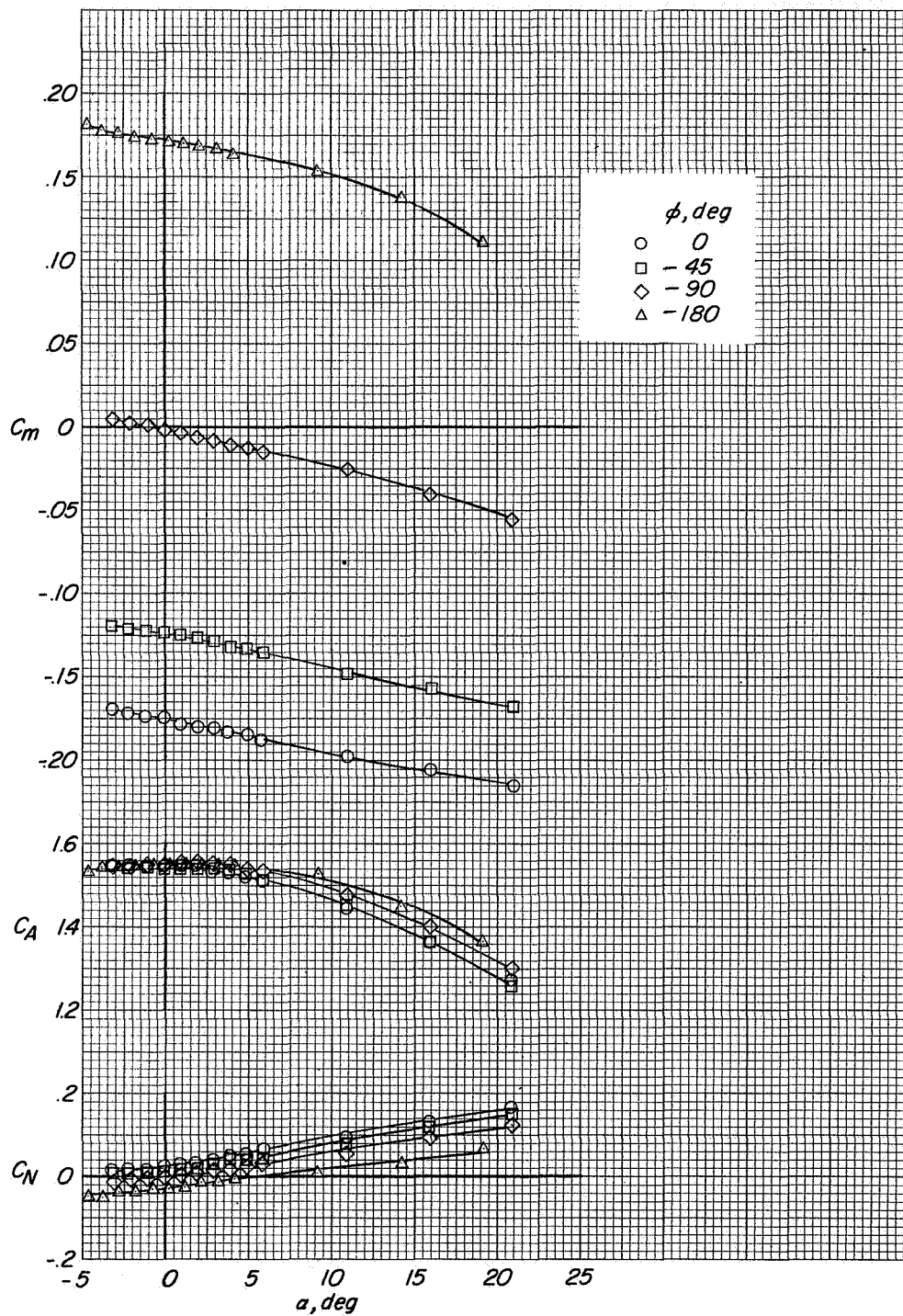


Figure 3.- Photograph of models.



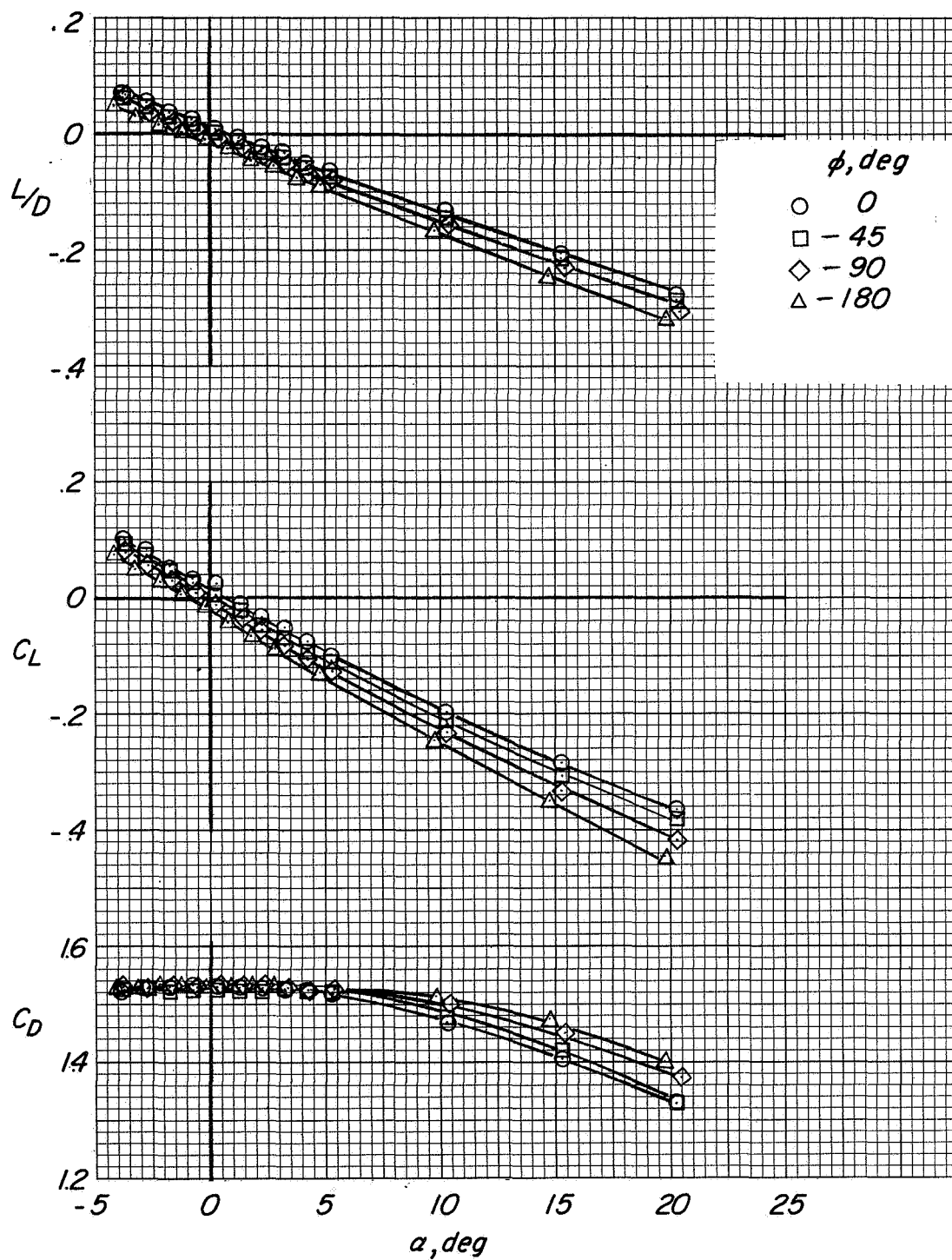
(a) $M = 2.30$.

Figure 4.- Longitudinal aerodynamic characteristics of configuration 1 (raked-off cone). $R = 1.09 \times 10^6$.



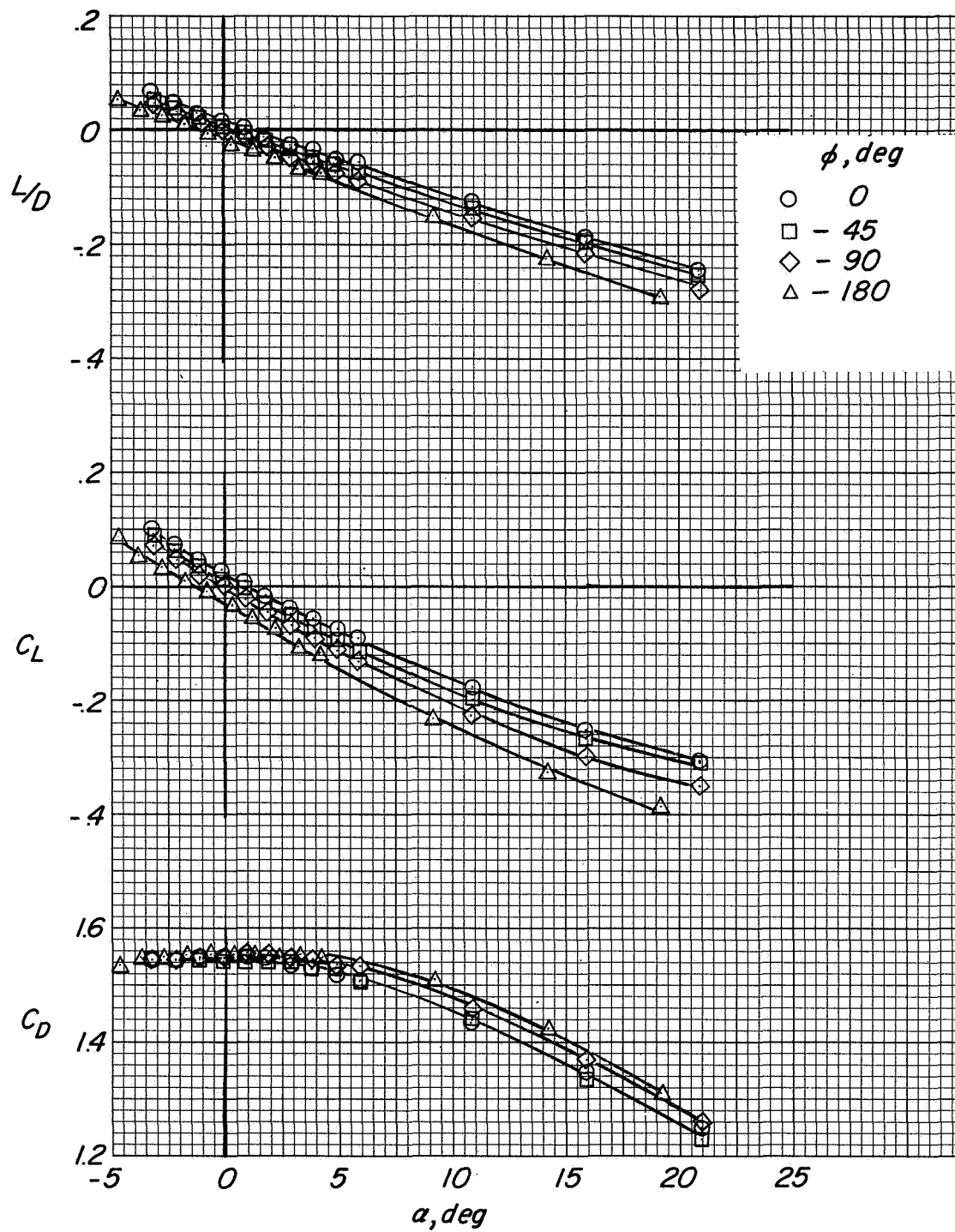
(b) $M = 4.63$.

Figure 4.- Concluded.



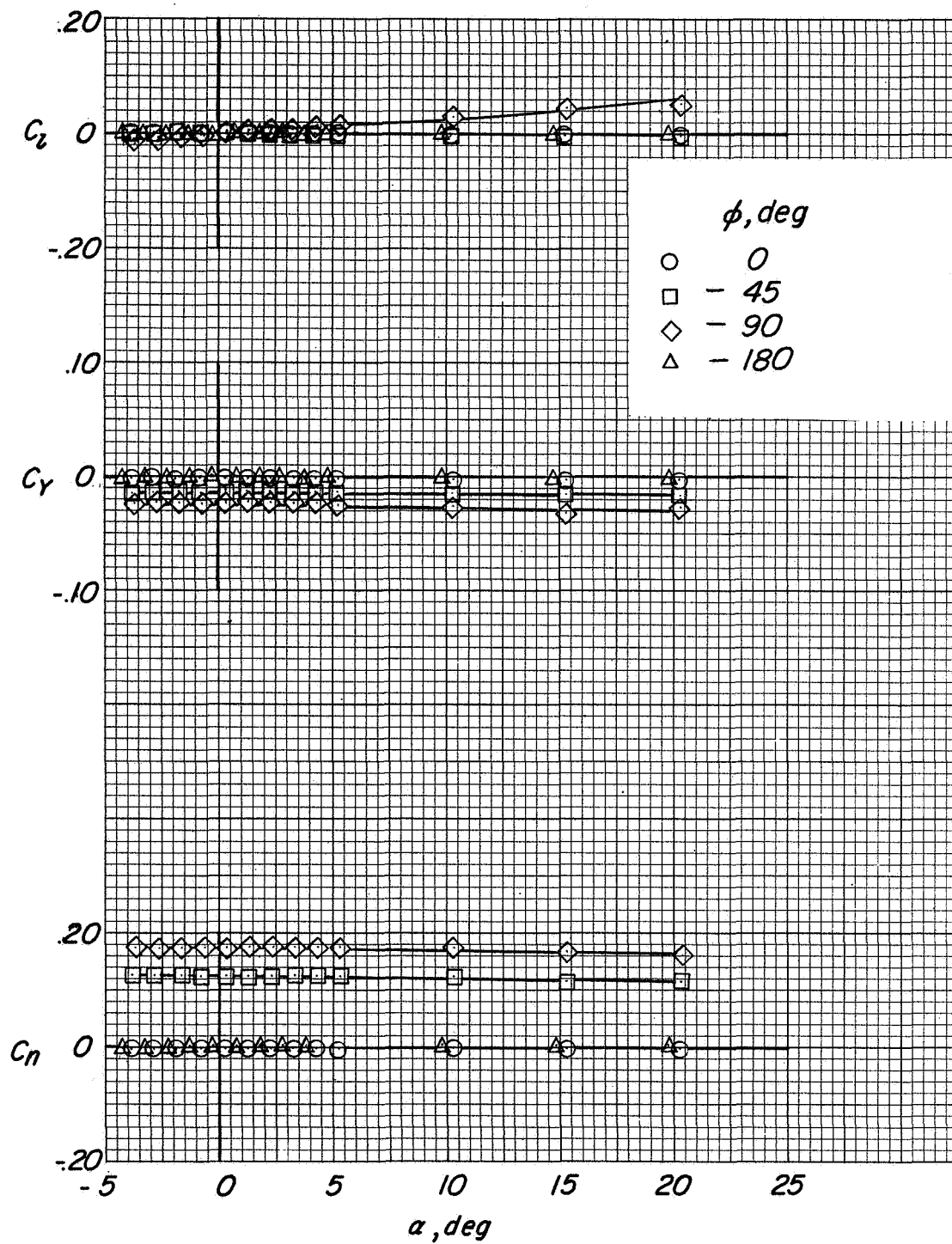
(a) $M = 2.30$.

Figure 5.- Aerodynamic characteristics with respect to the stability-axis system of configuration 1 (raked-off cone).



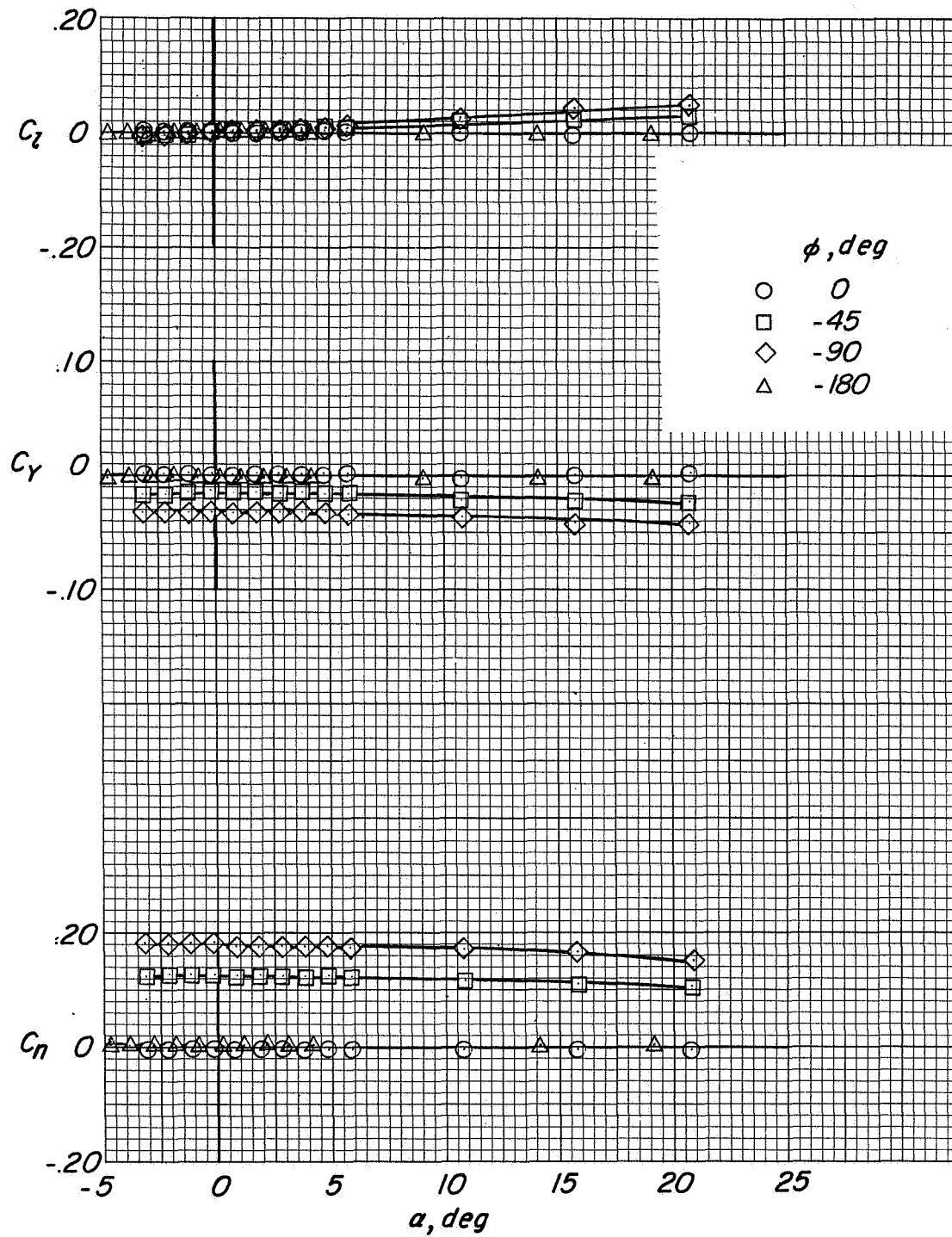
(b) $M = 4.63$.

Figure 5.- Concluded.



(a) $M = 2.30$.

Figure 6.- Static lateral aerodynamic characteristics of configuration 1 (raked-off cone).



(b) $M = 4.63$.

Figure 6.- Concluded.

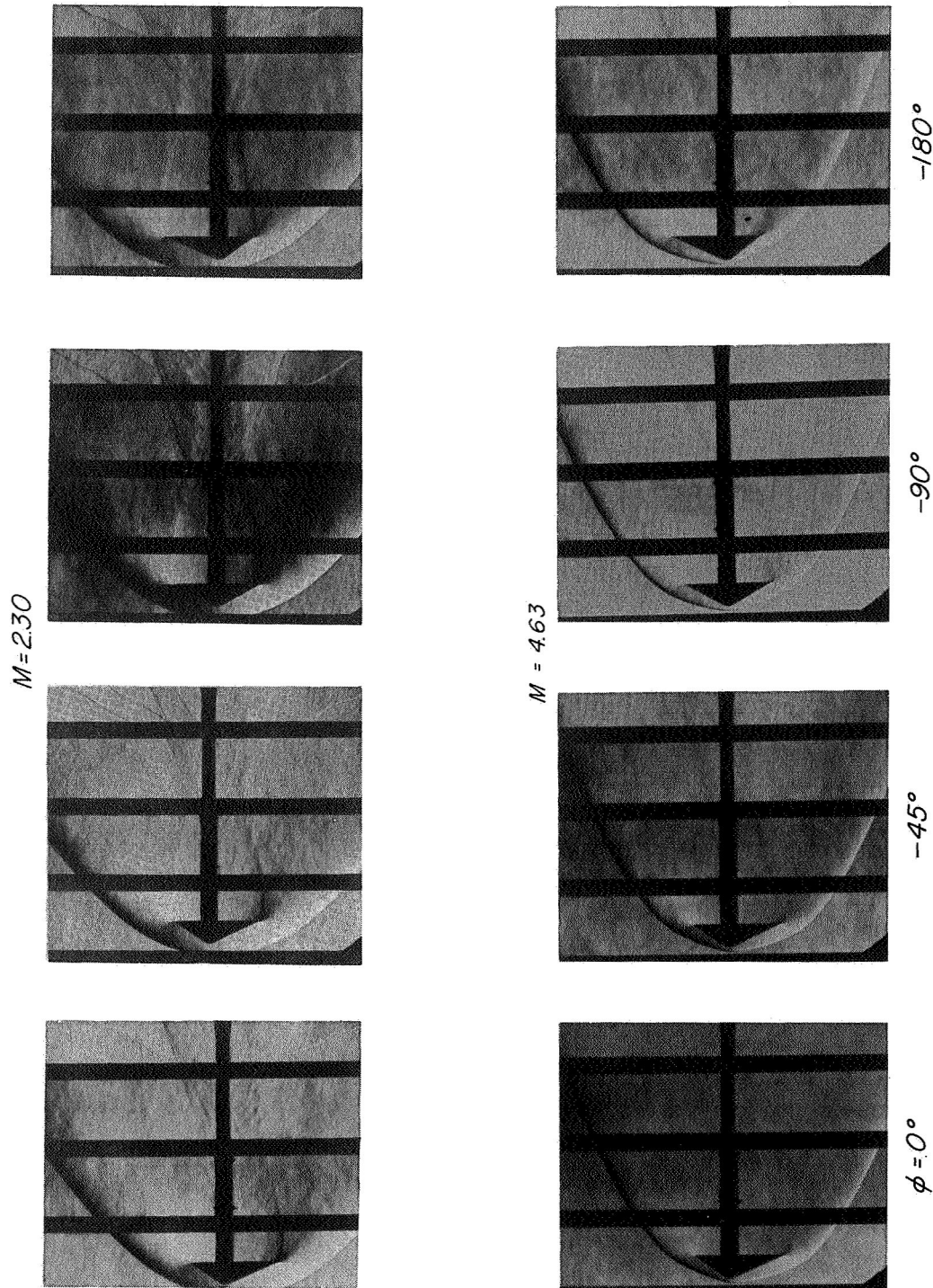
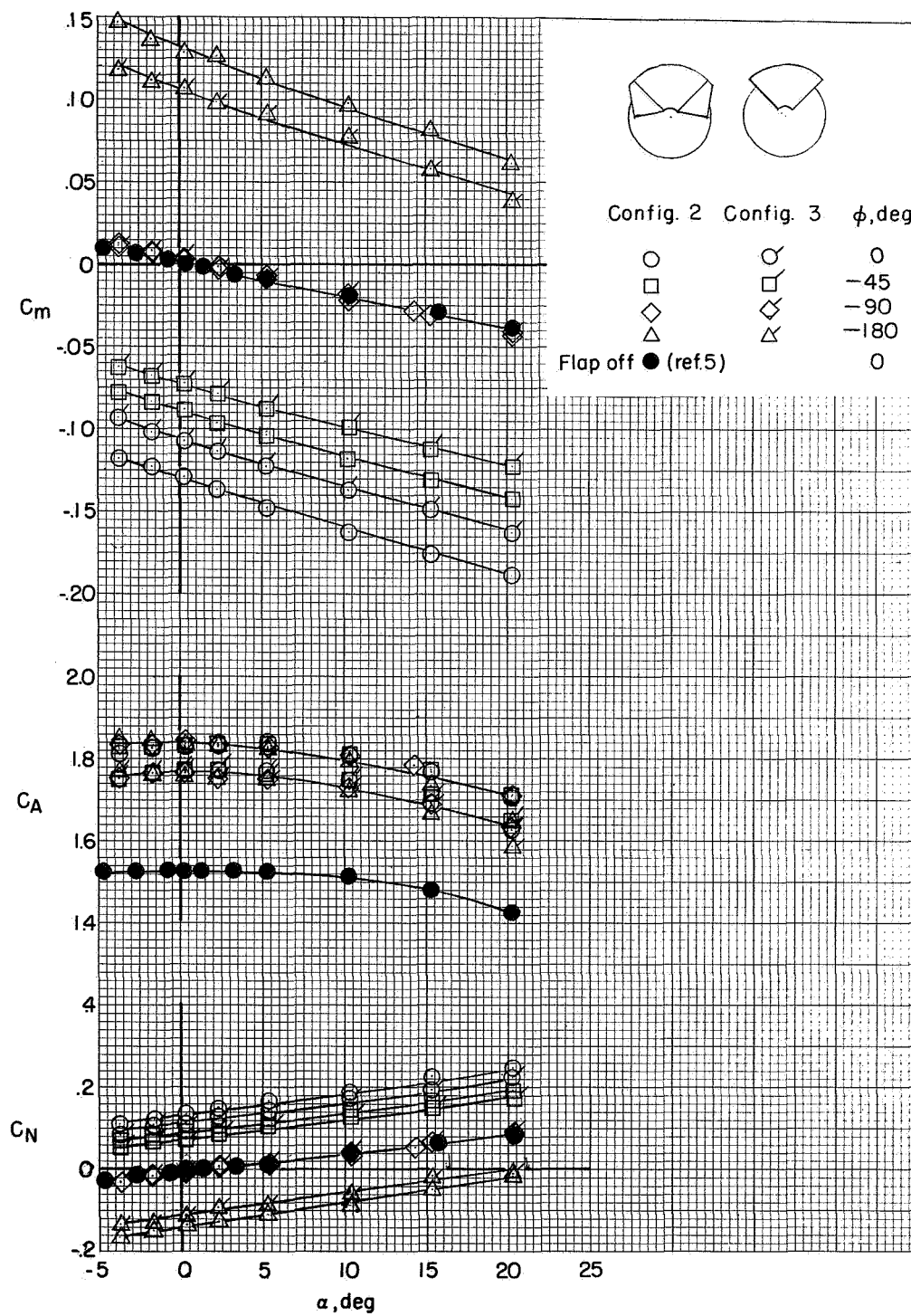
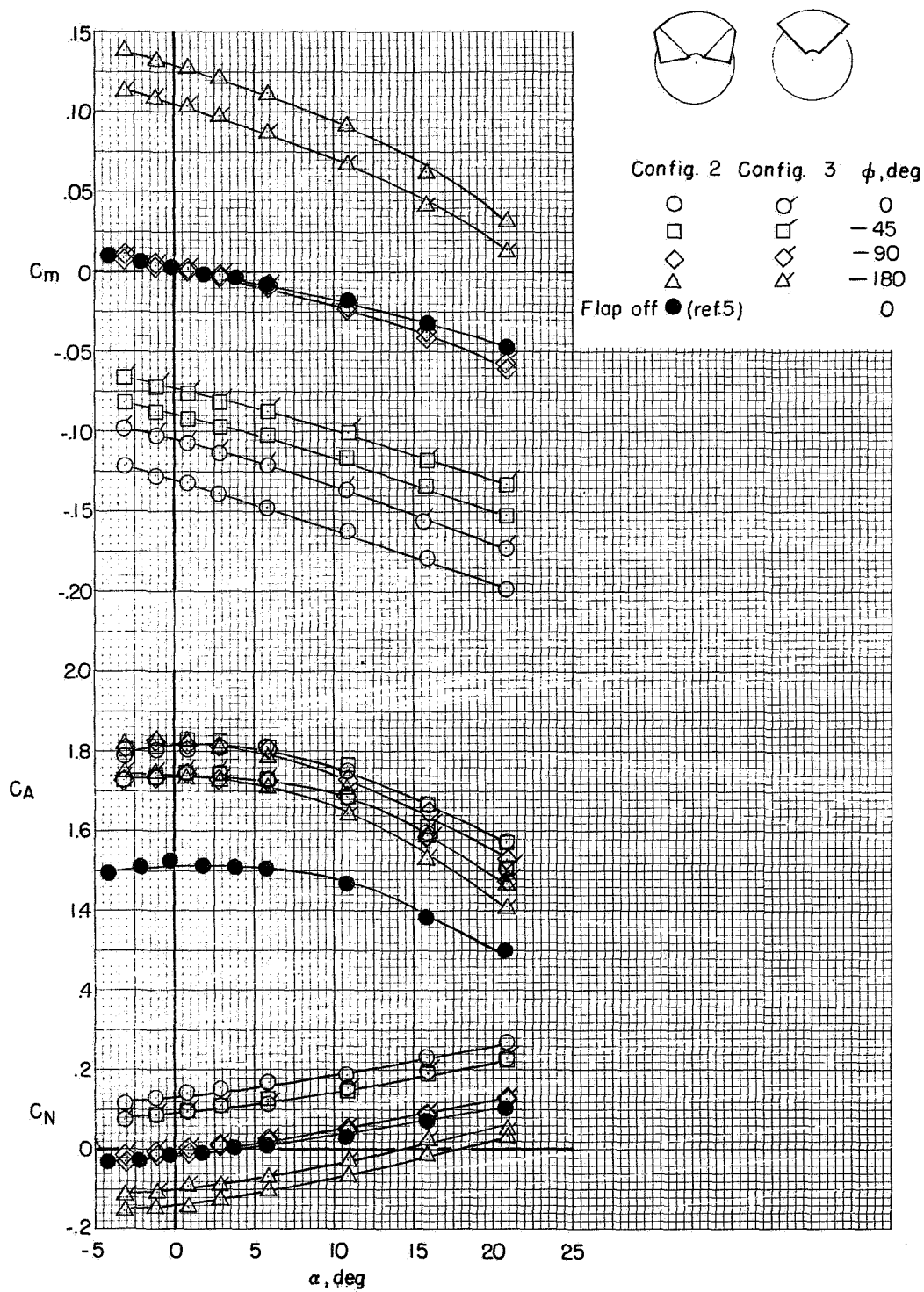


Figure 7.- Typical schlieren photographs of configuration 1 (raked-off cone). $\alpha = 0^\circ$.
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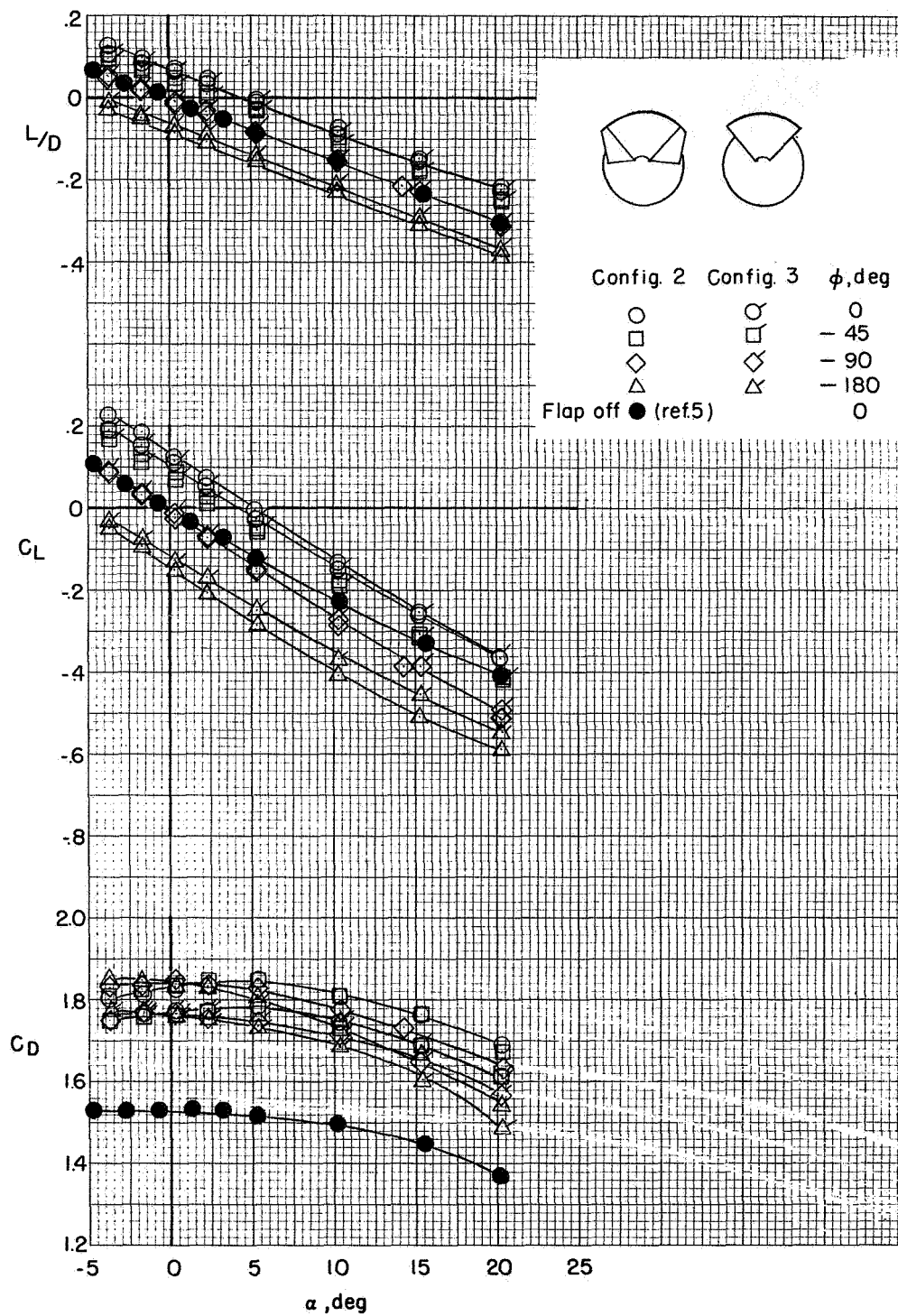
(a) $M = 2.30$.

Figure 8.- Longitudinal aerodynamic characteristics of configurations 2 and 3 (flapped cones).



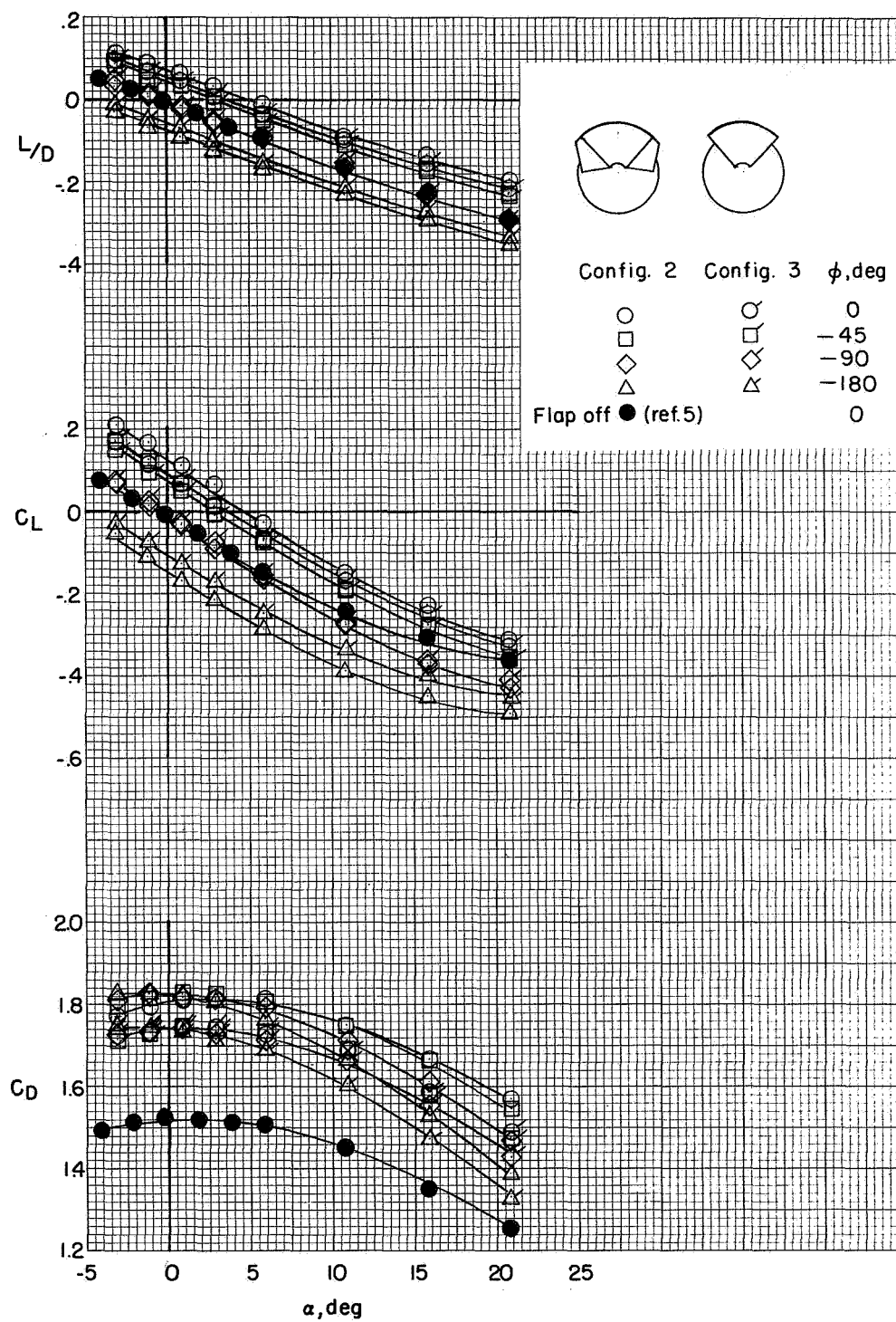
(b) $M = 4.63$.

Figure 8.- Concluded.



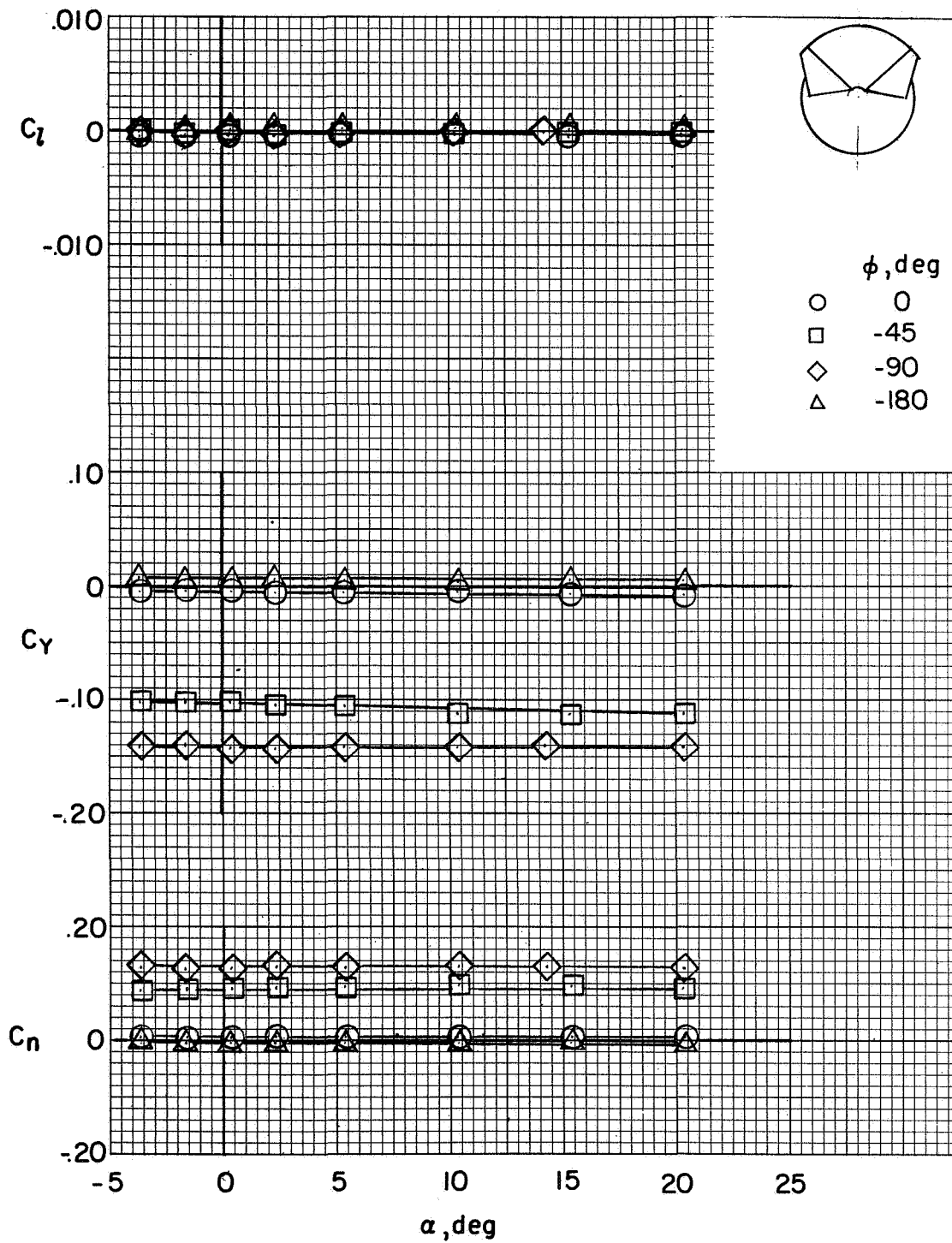
(a) $M = 2.30$.

Figure 9.- Aerodynamic characteristics with respect to the stability-axis system of configurations 2 and 3 (flapped cones.).



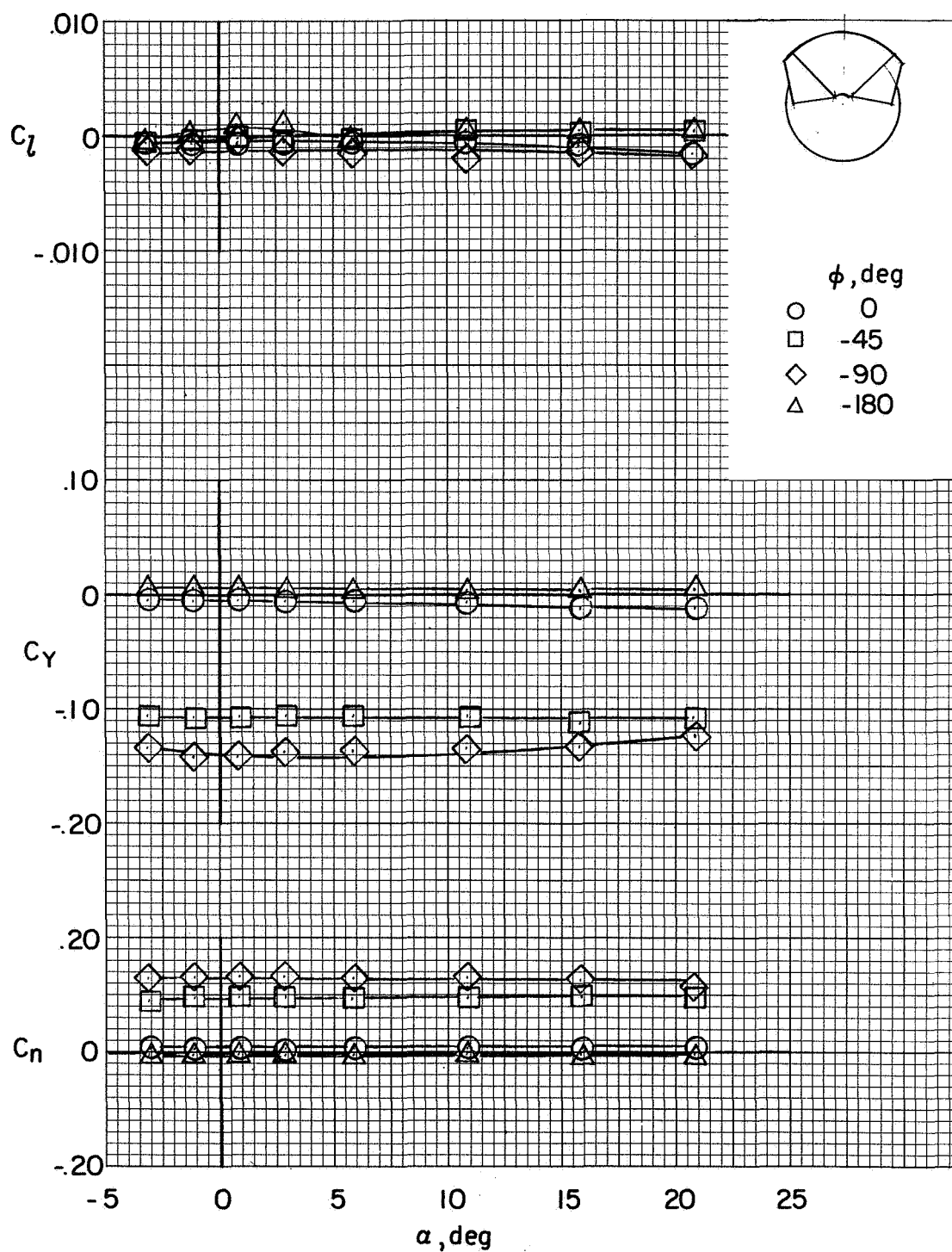
(b) $M = 4.63$.

Figure 9.- Concluded.



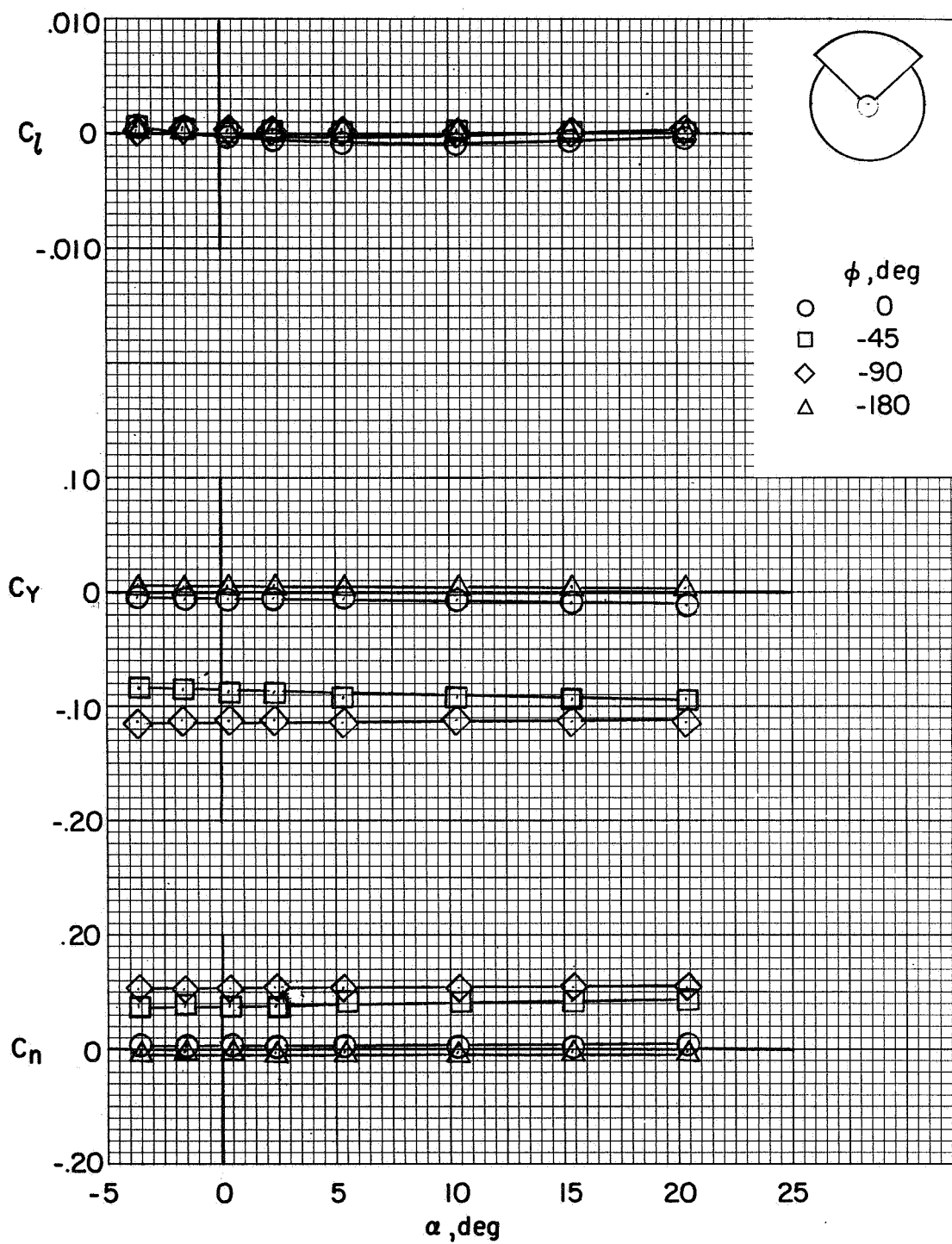
(a) Configuration 2. $M = 2.30$.

Figure 10.- Static lateral aerodynamic characteristics of flapped cones.



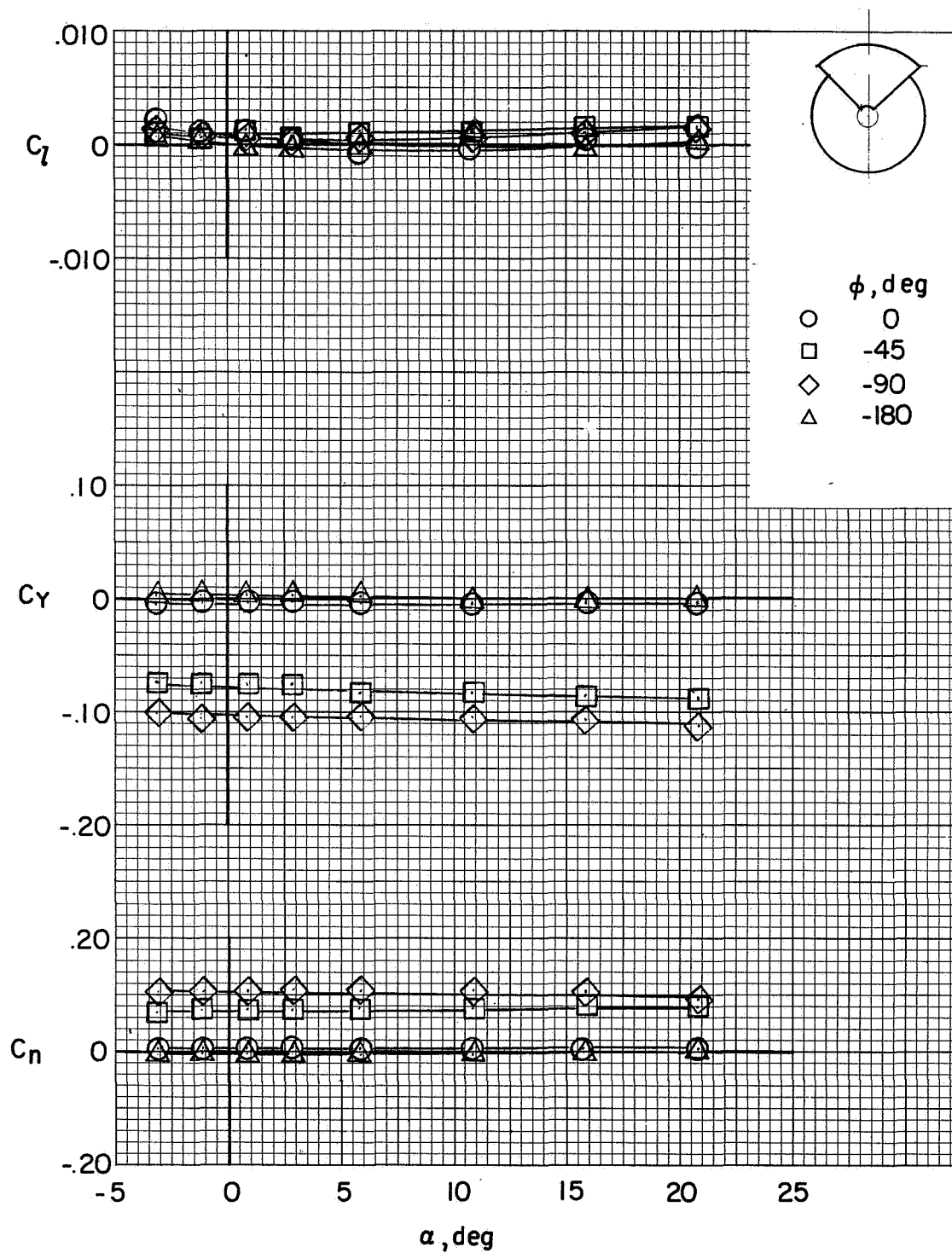
(b) Configuration 2. $M = 4.63$.

Figure 10.- Continued.



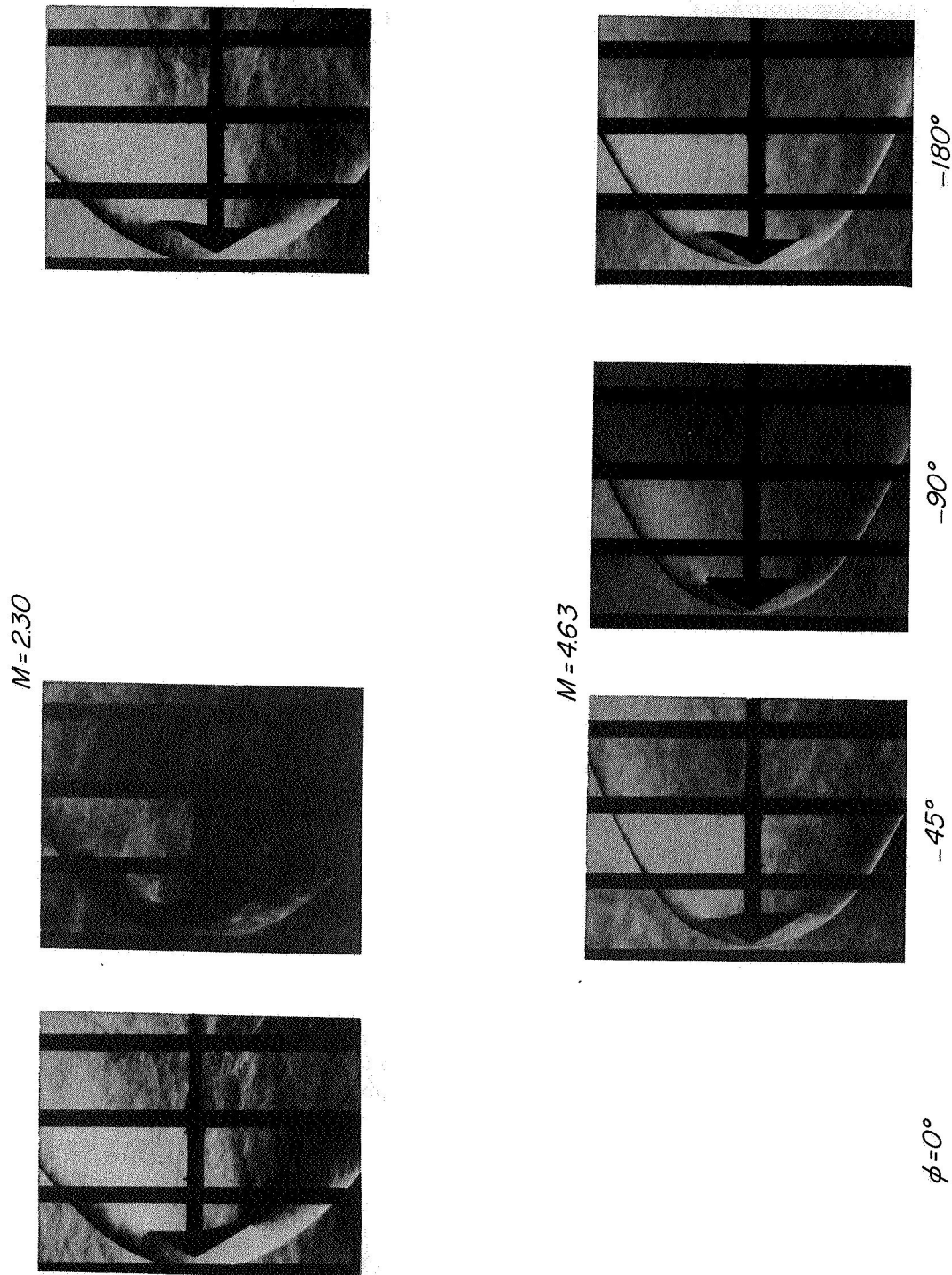
(c) Configuration 3. $M = 2.30$.

Figure 10.- Continued.



(d) Configuration 3. $M = 4.63$.

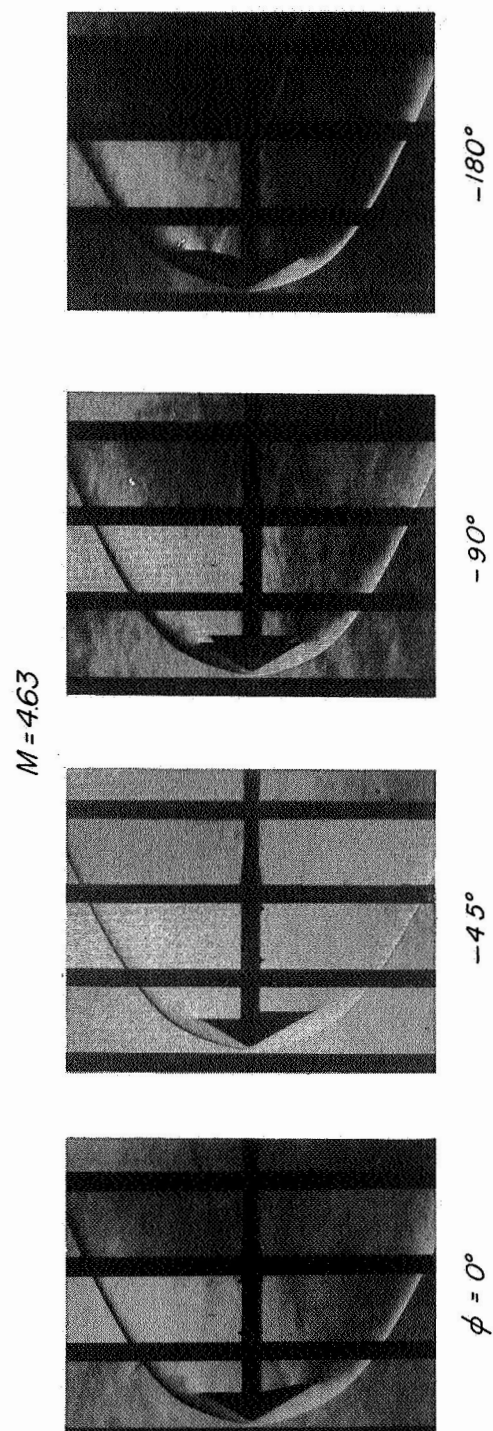
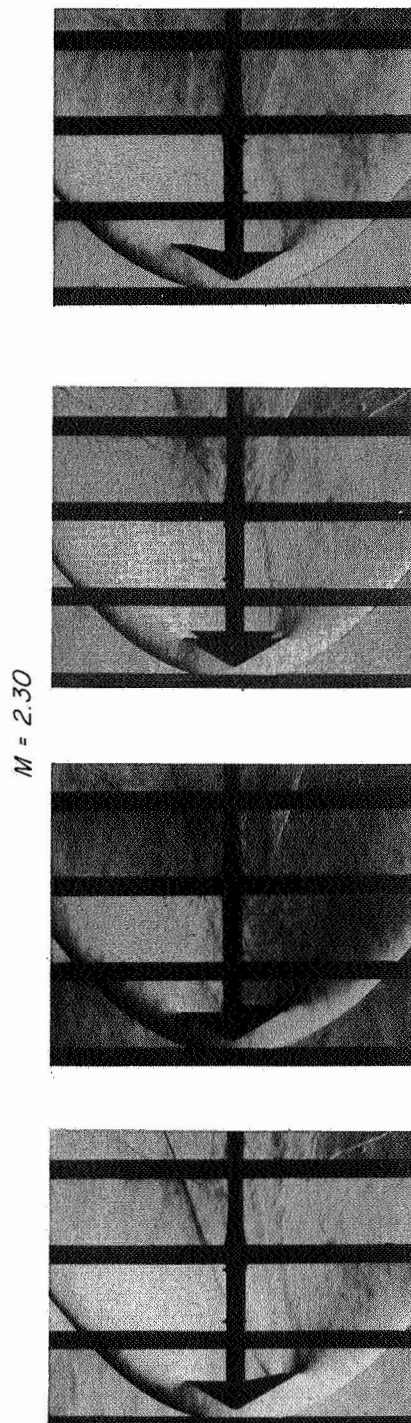
Figure 10.- Concluded.



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(a) Configuration 2.

Figure 11.- Typical schlieren photographs of flapped cones.



L-72-2433

(b) Configuration 3.

Figure 11.- Concluded.



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